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(54) Variable-pitch Belt-and-pulley Mechanism and Method of Producing Component Belt for Use Therein

(57) A variable-pitch belt-and-pulley mechanism comprises two pulleys each having a pair of bevelled disks (6, 6') axially movable toward and away from each other and forming therebetween a circumferential groove (8) having a V-shaped cross section and continuously variable in width. An endless belt assembly (5) passes between the pulleys (1, 2) and comprises a belt structure (9) including at least one flexible component belt (20) of closed loop form and a series of carrier blocks (11; 11') disposed in contact with one another throughout the length of the belt structure (9), wherein the component belt (20) is produced by plastically deforming an elongated strip of ductile metal in such a manner that the strip has induced therein a residual tensile stress which is at a maximum at the inner surface of the component belt (20) and a residual compressive stress which is at a maximum at the outer surface Po of the belt (20).

FIG. 6

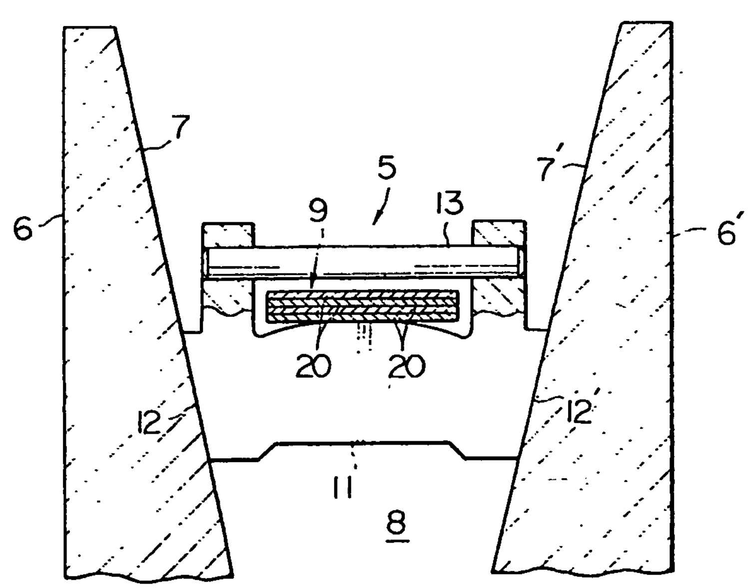


FIG. 1
PRIOR ART

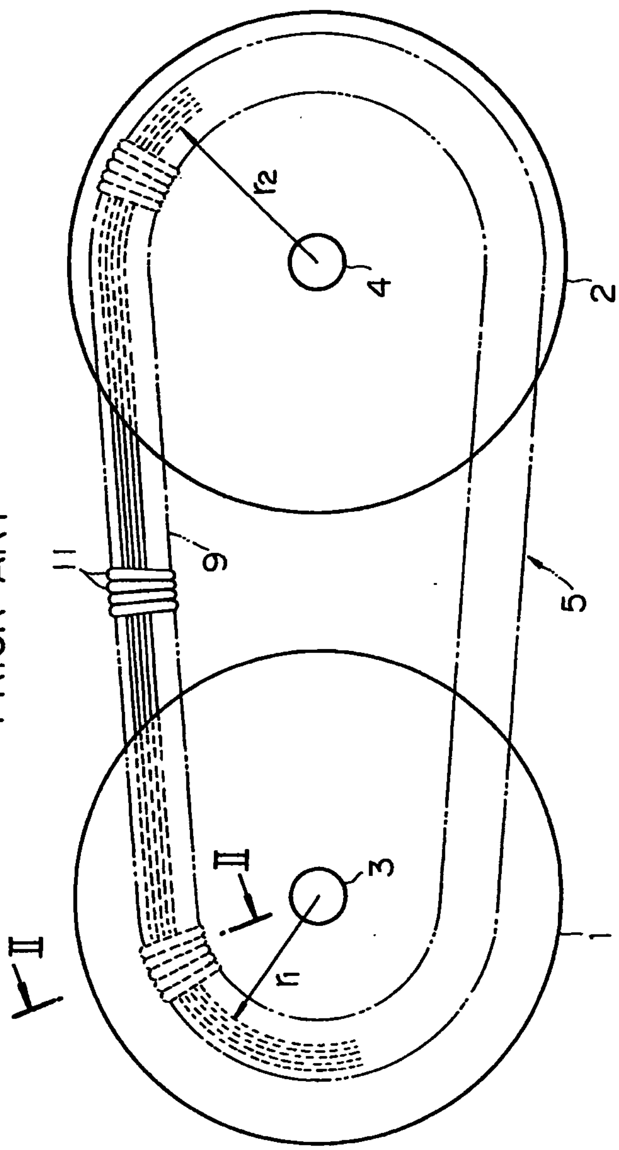


FIG. 2
PRIOR ART

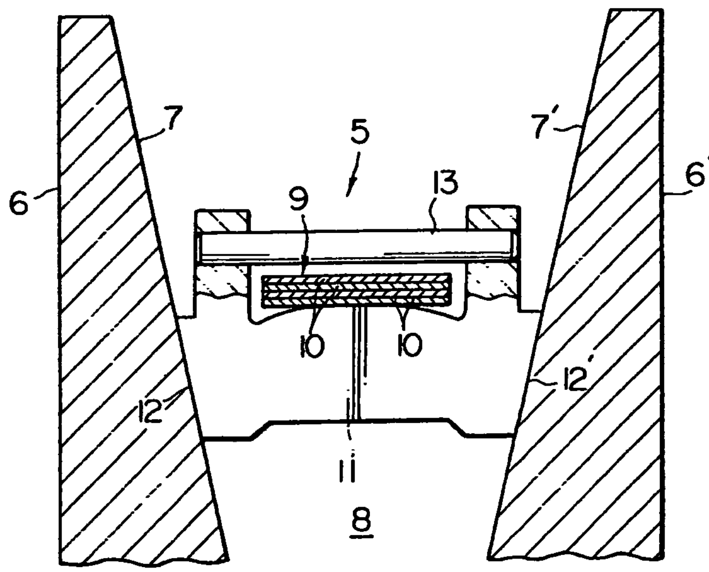


FIG. 3
PRIOR ART

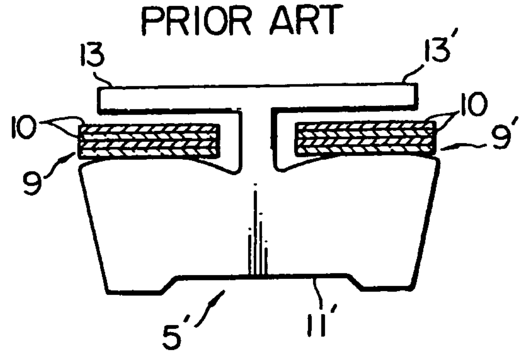


FIG. 4

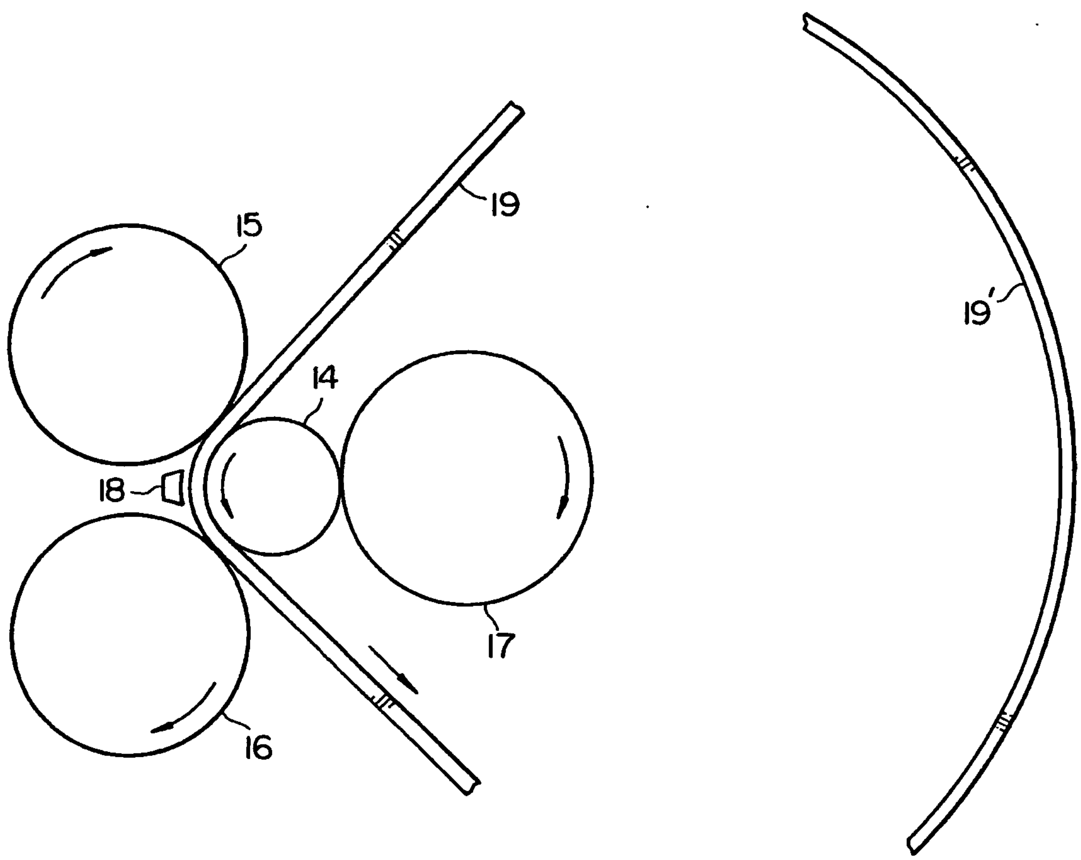


FIG. 5

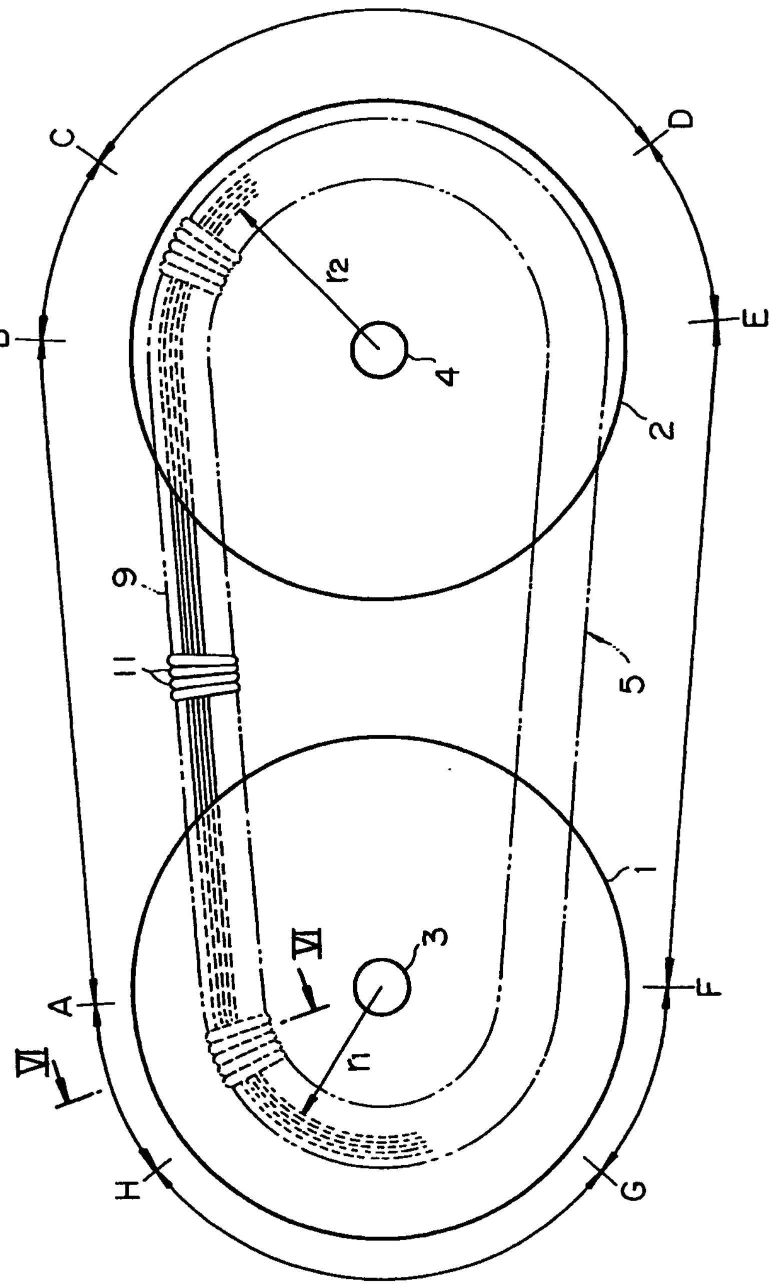


FIG. 6

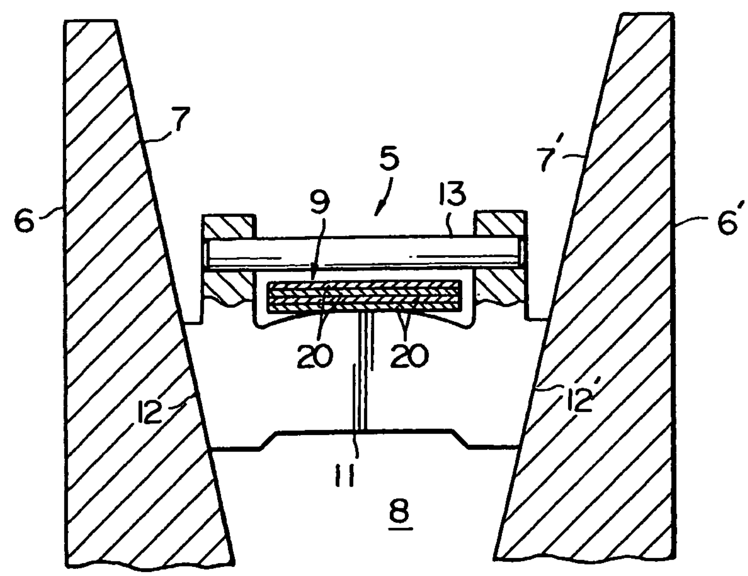


FIG. 7

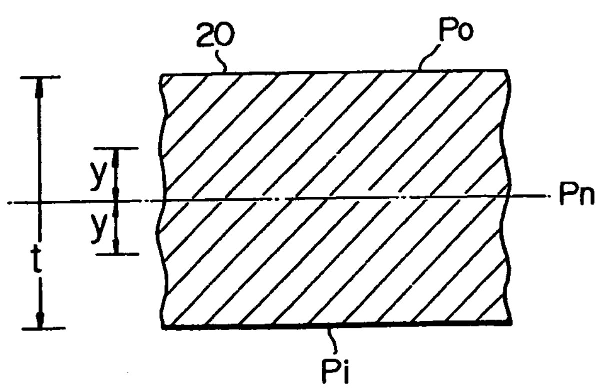


FIG. 8A

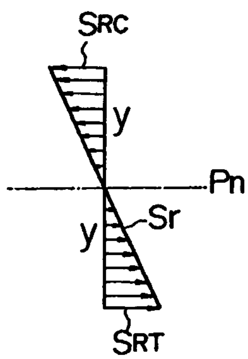


FIG. 8B

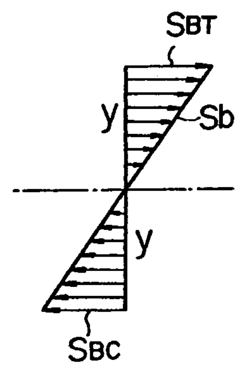


FIG. 8C

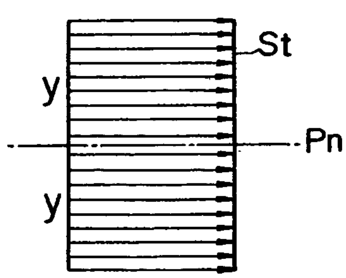


FIG. 8D

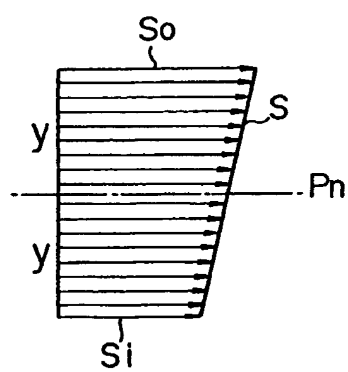
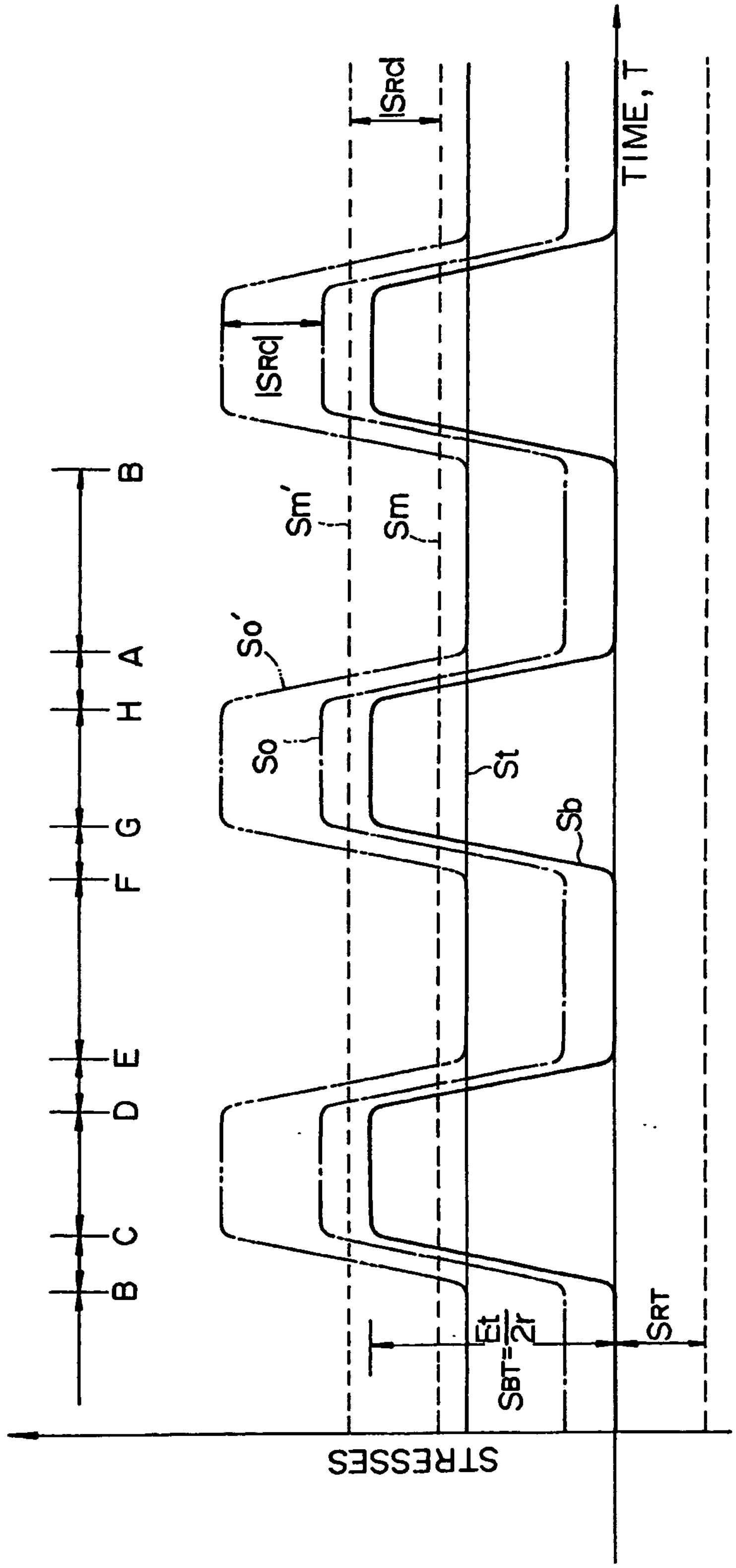


FIG. 9



TIME, T
STRESSES
B
C
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E
F
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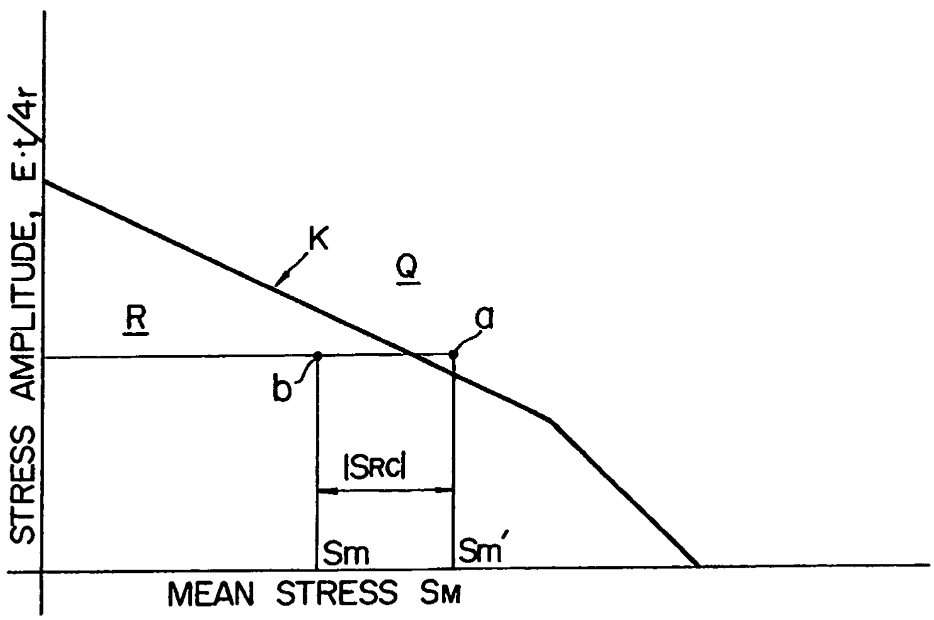
A
B
|SRC|
|SRC|
Sm'
Sm
So'
So
St
Sb
SBT=Et/2r
SRT

FIG. 10



SPECIFICATION

Variable-Pitch Belt-and-Pulley Mechanism and Method of Producing Component Belt for Use Therein

The present invention relates to a variable-pitch belt-and-pulley mechanism using an endless V-belt assembly and further to a method of producing a component belt to form part of such a belt assembly.

In accordance with one aspect of the present invention, there is proposed a variable-pitch belt-and-pulley mechanism which comprises two pulleys each having a pair of frusto-conical inner faces forming therebetween a circumferential groove having a substantially trapezoidal cross section which is continuously variable in width so that each of the pulleys has a continuously variable effective radius, and an endless belt assembly passed between the pulleys and comprising at least one belt structure including at least one flexible component belt of loop form having inner and outer surfaces and series of carrier blocks disposed in contact with one another throughout the length of the belt structure and each having an outer surface portion which are held in frictional contact with the inner face of the belt structure and a pair of inclined side faces which are held in frictional contact with the frusto-conical inner faces, respectively, of each of the pulleys, wherein the component belt of the belt structure has a residual tensile stress which becomes maximal at the inner surface of the component belt and a residual compressive stress which becomes maximal at the outer surface of the component belt.

In accordance with another aspect of the present invention, there is proposed a method of producing a flexible belt for use in a variable-pitch belt-and-pulley mechanism of the above described nature, wherein the flexible belt is produced by plastically deforming an elongated strip of ductile metal in such a manner that the strip is caused to curve with a predetermined radius of curvature and that the curved strip has inner and outer faces which are to constitute the outer and inner surfaces, respectively, of the belt when the curved strip is rendered into endless loop form. In this instance, the predetermined radius of curvature as above mentioned is preferably pulleys.

Drawbacks of a prior art variable-pitch belt-and-pulley mechanism and the features and advantages of a belt-and-pulley mechanism according to the present invention and of a method of producing a component belt for use therein will be clearly understood from the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a side view of a conventional variable-pitch belt-and-pulley mechanism of the type to which the present invention generally appertains;

Fig. 2 is a fragmentary sectional view taken, to an enlarged scale, along the line II—II in Fig. 1;

Fig. 3 is a cross sectional view of an endless belt assembly forming part of a known modification of the belt-and-pulley mechanism illustrated in Figs. 1 and 2;

Fig. 4 is a schematic view showing an example of the roller arrangement forming part of a rolling mill which may be used to carry out a method according to the present invention;

Fig. 5 is a side view of an embodiment of a variable-pitch belt-and-pulley mechanism according to the present invention;

Fig. 6 is a fragmentary sectional view taken, to an enlarged scale, along line VI—VI in Fig. 5;

Fig. 7 is a fragmentary sectional view of a component belt included in the variable-pitch belt-and-pulley mechanism embodying the present invention;

Fig. 8A is a graphic representation of the distribution of residual stress across the thickness of the component belt illustrated in Fig. 7;

Fig. 8B is a graphic representation of the distribution of the bending stress to be induced across the thickness of the component belt illustrated in Fig. 7 when the component belt is forced to curve;

Fig. 8C is a graphic representation of the distribution of the tensile stress to be induced across the thickness of the component belt illustrated in Fig. 7 during operation of the belt-and-pulley mechanism embodying the present invention;

Fig. 8D is a graphic representation of the distribution of the combined residual, bending and tensile stresses to appear across the thickness of the component belt illustrated in Fig. 7 during operation of the belt-and-pulley mechanism embodying the present invention;

Fig. 9 is a graphic diagram showing changes, in terms of time, in the various stresses which are to appear in component belt of the prior-art belt-and-pulley mechanism illustrated in Figs. 1 and 2 and the component belt illustrated in Fig. 7; and

Fig. 10 is an amplitude-stress diagram showing the relationship between the mean stress and the amplitude of the stress applied to a metal.

A conventional variable-pitch belt-and-pulley mechanism of the type to which the present invention apertains is shown in, for example, Japanese Patent Publication No. 55—6783. As illustrated in Fig. 1 of the drawings, the prior-art belt-and-pulley mechanism comprises two V-grooved pulleys which consist of first and second pulleys 1 and 2 which are carried on and rotatable with parallel shafts 3 and 4, respectively, and an endless belt assembly 5 passed between the pulleys 1 and 2. As illustrated partially and to an enlarged scale in Fig. 2, each of the pulleys 1 and 2 is largely composed of a pair of bevelled disks 6 and 6′ having frusto-conical inner faces 7 and 7′, respectively, which form therebetween a circumferential groove 8 having a V-shaped or trapezoidal cross section. On the other hand, the endless belt assembly 5 comprises a laminar belt structure 9 composed of a plurality of component

belts 10 of loop form and a series of carrier blocks 11 disposed in contact with one another throughout the length of the belt structure 9. Each of the carrier blocks 11 has an outer surface portion held in frictional contact with the inner face of the belt structure 9, viz., the inner face of the innermost one of the laminated component belts 10 and a pair of inclined side faces 12 and 12′ which are held in frictional contact with the frusto-conical inner faces 7 and 7′ of the disks 6 and 6′, respectively. Each carrier block 11 further has a pair of side lug portions, between which the belt structure 9 longitudinally passes. A retainer element 13 extends between these lug portions and prevents the endless belt structure 9 from being disengaged from the carrier block 11.

One of the shafts such as, for example, the shaft 3 carrying the first pulley 1 thereon is operatively connected to drive means (not shown). When the drive means is in operation, the shaft 3 and accordingly the first pulley 1 thereon are driven for rotation about the center axis of the shaft 3. The rotation of the first pulley 1 is transmitted to the belt assembly 5 through the frictional engagement between the frusto-conical inner faces 7 and 7′ of the disks 6 and 6′ constituting the pulley 1 and the inclined side faces 12 and 12′ of each of the carrier blocks 11 contacting the disks 6 and 6′. The carrier blocks 11 riding on the disks 6 and 6′ of the first pulley 1 are thus urged to turn together with the pulley and, in turn urge the belt structure 9 to travel by reason of the frictional engagement between the inner face of the belt structure 9 and the respective outer surface portions of the carrier blocks 11 riding on the disks 6 and 6′. The endless belt assembly 5 as a whole is thus caused to travel between the first and second pulleys 1 and 2. The travelling movement of the belt assembly 5 is transmitted to the disks 6 and 6′ constituting the second pulley 2 through the frictional engagement between the frusto-conical inner faces 7 and 7′ of the disks 6 and 6′ of the pulley 2 and the inclined side faces 12 and 12′ of each of the carrier blocks 11 riding on the disks 6 and 6′ of the pulley 2, thereby causing the pulley 2 and the shaft 4 to rotate about the center axis of the shaft 4.

At least one of the disks 6 and 6′ of each of the pulleys 1 and 2 is keyed or splined to each of the shafts 3 and 4, respectively, and is thus axially movable steplessly toward and away from the other of the disks. Thus, the circumferential groove 8 between the frusto-conical inner faces 7 and 7′ of the disks 6 and 6′ of each of the pulleys 1 and 2 is continuously variable in width so that each pulley has a continuously variable effective radius which is denoted by r_1 for the first pulley 1 and by r_2 for the second pulley 2 in Fig. 1.

In Fig. 3 of the drawings is illustrated a known modification of the endless belt assembly 5. The modified endless belt assembly, now designated in its entirety by 5′, comprises a pair of laminar belt structures 9 and 9′ each composed of a plurality of components belts 10 of loop form and a series of carrier blocks only one of which is shown and designated by 11′. Each of the carrier blocks 11′ has a pair of parallel outer surface portions respectively having the belt structure 9 and 9′ received thereon. Each of the carrier blocks 11′ further has a pair of retaining portions 13 and 13′ for precluding the endless belt structures 9 and 9′ from being disengaged from each carrier block.

During operation of the variable-pitch belt-and-pulley mechanism described with reference to Figs. 1 and 2, the individual carrier blocks 11 riding on the bevelled disks 6 and 6′ of each of the pulleys 1 and 2 are urged to move radially outwardly away from the axis of rotation of the pulley and produce an intense tensile force in each of the component belts 10 of the belt structure 9. Furthermore, the belt structure 9 is forced to partially curve when making a turn on each of the pulleys 1 and 2. A bending stress is thus induced periodically in each belt component 10 of the belt structure 9 and is combined with the tensile stress produced throughout the loop of the component belt. The combined tensile and bending stresses may jeopardize the belt structure 9 or each of the component belts 10 of the structure 9 to invite failures in the material thereof.

The tensile stress to be induced in each belt component 10 of the belt structure 9 may be reduced by increasing the number of the component belts 10 to construct the belt structure 9 or increasing the width of the belt structure 9. If, furthermore, the force by which the carrier block 11 is to be urged to move radially outwardly by the disks 6 and 6′ of each pulley is regulated properly depending upon the magnitude of the load to be transmitted through the belt structure 9, the tensile force to be applied to each component belt 10 could also be reduced to a significant degree.

The bending stress induced in each of the component belts 10 becomes maximal in absolute value at each of the inner and outer surfaces of the component belt. If in this instance, every component belt 10 is assumed to have a thickness t, the maximum bending stress, denoted by S_B, to be produced in one of the component belts 10 of the belt structure 9 is dictated solely by the thickness t of the component belt 10, the radius of curvature r with which the component belt 10 is caused to turn on one of the pulleys 1 and 2, and Young's modulus E of the particular component belt 10 and is given by

$$S_B = E \cdot t/2r.$$

The maximum bending stress S_B produces tension at the outer surface of the component belt 10 and compression at the inner surface of the belt 10.

The maximum bending stress S_B thus appearing at each of the inner and outer surfaces of the component belt 10 cannot be reduced by increasing the width of the belt structure 9 or the number of the component belts 10 to construct

the belt structure 9. If the radius of curvature with which the component belt 10 is to travel round each of the pulleys 1 and 2 is made smaller to provide compact and wieldy construction, the result will be that the maximum bending stress S_B to be induced in the component belt 10 becomes larger as will be readily understood from the above equation.

Each of the component belts 10 of the belt assembly 9 is subjected to bending forces at all times when the belt 10 is turning round the pulleys 1 and 2 without respect to the presence or absence and the magnitude of a load applied to the belt 10. For this reason, the bending forces to be applied to each of the component belts 10 cannot be regulated depending upon the magnitude of the load to be transmitted through the belt assembly 5.

Throughout the operation of the belt-and-pulley mechanism, furthermore, the belt structure 9 experiences alternate successions of straight travel between the pulleys 1 and 2 and a turning motion round each of the pulleys 1 and 2. Each of the component belts 10 of the belt structure 9 is thus subjected not only to the action of a sustained tensile stress but to the action of repeated bending stresses. When the belt structure 9 is turning round each of the pulleys 1 and 2, therefore, each of the component belts 10 is subjected to both of the action of the tensile stress and the action of the bending stress. Periodic application of these stresses on each of the component belts 10 promotes the fatigue of the belt and results in a shortened service life of the belt structure 9.

The present invention contemplates resolution of these problems by preliminarily producing in each of the component belts 10 of the belt structure 9 a residual compressive stress which increases toward the outer surface of the belt and a residual tensile stress which increases toward the inner surface of the component belt 10.

Fig. 4 of the drawings shows an example of the roller arrangement forming part of a rolling mill which may be used to produce such a component belt. The roller arrangement comprises the combination of first, second and third work rolls 14, 15 and 16 and one backup roll 17 associated with the first work roll 14. The first work roll 14 is spaced in parallel from the second and third work rolls 15 and 16 and forms a primary gap between the first and second work rolls 14 and 15 and a second gap between the first and third work rolls 14 and 16. The first work roll 14 is forced toward the respective center axes of the second and third rolls 15 and 16 by means of the backup roll 17 which is held in pressing contact with the first roll 14. If a hot rolling process is preferred, a heating device 18 may be positioned adjacent the primary and secondary gaps as shown.

During operation, an elongated strip 19, of ductile metal such as sheet steel having a suitable thickness is longitudinally passed first through the primary gap between the first and second work rolls 14 and 15 and thereafter through the secondary gap between the first and third work rolls 14 and 16. At least one of the work rolls such as the first work roll 1 is positively driven for rotation about the center axis thereof by drive means such as a motor (not shown). The remaining work rolls such as the second and third work rolls 15 and 16 are thus driven for rotation about the center axis thereof in directions opposite to the direction of rotation of the first work roll 14 by the strip 19 gripped between the work roll 14 and each of the work rolls 15 and 16. The backup roll 17 is held in pressing and rolling engagement with the first work roll 14 and is driven for rotation about the center axis thereof also in a direction opposite to the direction of rotation of the work roll 14.

The primary gap between the first and second works rolls 14 and 15 is slightly smaller than the thickness of the supplied strip 19 and the secondary gap between the first and third work rolls 14 and 16 is slightly smaller than the primary gap and substantially equal to the desired thickness of the product to be finally obtained. The supplied strip 19 is thus in two consecutive steps reduced in thickness and elongated in a predetermined ratio and has a predetermined thickness t after the strip 19 is passed through the primary and secondary gaps.

When the strip 19 of sheet steel is thus rolled, the strip is plastically deformed throughout the length thereof. In this instance, the setups of the roller arrangement are selected so that the strip 19 is deformed into a strip 19′ which is curved with a predetermined radius of curvature. The strip 19′ thus curved has a residual compressive stress S_{RC} at the inner surface of the strip and a residual tensile stress S_{RT} at the outer surface of the strip. If, in this instance, the predetermined radius of curvature with which the strip 19′ is curved as a result of the plastic deformation is denoted by ρ, the above mentioned residual compressive stress S_{RC} is written as

$$S_{RC} = -E \cdot t/2\rho,$$

while the above mentioned residual tensile stress S_{RT} is written as

$$S_{RT} = E \cdot t/2\rho,$$

where t represents the thickness of the strip 19 finally rolled.

Figs. 5 and 6 shows an embodiment of a variable-pitch belt-and-pulley mechanism according to the present invention. The embodiment of the belt-and-pulley mechanism herein shown is similar in construction to the prior-art mechanism described with reference to Figs. 1 and 2. The members and elements of the embodiment shown in Figs. 5 and 6 are thus designated by the same reference numerals as those allocated to their respective counterparts in the prior-art mechanism of Figs. 1 and 2.

In the embodiment illustrated in Figs. 5 and 6, the laminar belt structure 9 forming part of the

endless belt assembly 5 is composed of a plurality of component belts 20 of loop form. Each of the component belts 20 is constituted by the curved strip 19′ produced in the above described manner. In this instance, it is important that the curved strip 19′ be deformed to loop in such a manner that the inner and outer faces of the strip 19′ constitute the outer and inner surfaces, respectively, of the resultant component belt 20. When the strip 19′ having free opposite ends and curved with the radius of curvature ρ is thus rendered into the form of, for example, a closed circular loop having a radius ρ', the residual compressive and tensile stresses at the outer and inner surfaces, respectively, of the particular belt component become different from the above mentioned stresses S_{RC} and S_{RT} and are respectively expressed as

$$S_{RC'}=(E\cdot t/2)\cdot(1/\rho-1/\rho')$$

and

$$S_{RT'}=(E\cdot t/2)\cdot(1/\rho'-1/\rho).$$

As will be understood as the description proceeds and as will be apparent from the fact that the component belts 20 extend in part linearly between the pulleys 1 and 2, the radius ρ' of the component belt 20 of circular loop form is larger than the radius of curvature ρ of the curved strip 19′. When the belt assembly 5 is installed on the pulleys 1 and 2, however, the radius of curvature with which the component belt 20 is curved on each of the pulleys 1 and 2 is dictated by the effective radius of each pulley. In the following analysis into the stresses appearing in the component belt 20, therefore, the residual stresses in the component belt 20 will be deemed as being equal to those induced in the curved strip 19′.

During operation of the belt-and-pulley mechanism embodying the present invention, each of the component belts 20 of the belt structure 9 travelling between the pulleys 1 and 2 is subjected to the stresses which consist of a residual stress S_r produced as described above, a bending stress S_b induced when the component belt 20 is making a turn on each of the pulleys, and a tensile stress S_t constantly induced in the component belt 20 stretched between the pulleys 1 and 2. When it is assumed that the distance from the neutral plane P*n* of the component belt 20 is denoted by *y* as shown in Fig. 7, the residual stress S_r distributed between the neutral plane P*n* and the outer surface (represented by P*o*) of the component belt 20 is given as

$$S_r=-E\cdot y/\rho$$

and acts as a compressive stress which becomes maximal at the outer surface P*o* of the component belt 20 as shown in the upper half of Fig. 8A. The maximum residual stress S_{RC} thus acting as the compressive stress is expressed as

$$S_{RC}=-E\cdot t/2\rho.$$

On the other hand, the residual stress S_r distributed between the neutral plane P*n* and the inner surface (indicated at P*i* in Fig. 7) of the component belt 20 is given as

$$S_r=E\cdot y/\rho$$

and acts as a tensile stress which becomes maximal at the inner surface P*i* of the component belt as shown in the lower half of Fig. 8A. The maximum residual stress S_{RT} acting as the tensile stress is expressed as

$$S_{RT}=E\cdot y/2\rho.$$

When, furthermore, it is assumed that the effective radii r_1 and r_2 of the first and second pulleys 1 and 2, respectively, are equal to each other and are commonly given as *r*, the bending stress S_b induced between the neutral plane P*n* and the outer surface P*o* of the component belt 20 is given as

$$S_b=E\,y/r$$

and acts as a tensile stress which becomes maximal at the outer surface P*o* of the component belt 20 as shown in the upper half of Fig. 8B. The maximum bending stress S_{BT} thus acting as the tensile stress is expressed as

$$S_{BT}=Et/2r.$$

On the other hand, the bending stress S*b* distributed between the neutral plane P*n* and the inner surface P*i* of the component belt 20 is given as

$$S_b=-Ey/r$$

and acts as a compressive stress which becomes maximal at the inner surface P*i* of the component belt 20 as shown in the lower half of Fig. 8B. The maximal bending stress S_{BC} acting as the compressive stress is expressed as

$$S_{BC}=-Et/2r.$$

The tensile stress S*t* constantly induced in the component belt 20 stretched between the pulleys 1 and 2 is uniformly distributed throughout the thickness *t* of the component belt 20 as graphically shown in Fig. 8C.

The combined stresses, denoted by S, which are in play between the neutral plane P*n* and the outer surface P*o* of the component belt 20 during operation of the belt-and-pulley mechanism is expressed in the form

$$\begin{aligned}S&=S_r+S_b+S_t\\&=E\cdot y(1/r-1/\rho)+S_t\end{aligned}$$

At the outer surface P*o* of the component belt 20, the combined stresses S*o* are given by

$$So=(E \cdot t/2) \cdot (1/r-1/\rho)+S_t.$$

On the other hand, the combined stresses S which are in play between the neutral plane *Pn* and the inner surface *Pi* of the component belt 20 during operation of the belt-and-pulley mechanism is expressed in the form

$$S=S_r+S_b+S_t=E \cdot y(-1/r+1/\rho)+S_t.$$

At the inner surface *Pi* of the component belt 20, the combined stressed *Si* are given by

$$Si=(E \cdot t/2) \cdot (-1/r+1/\rho)+S_t.$$

When the tensile stress S_t is zero, viz., there is no load being transmitted through the component belt 20, the stresses *So* and *Si* at the outer and inner surfaces *Po* and *Pi*, respectively are equal in absolute value to each other. When, on the other hand, the tensile stress S_t assumes a positive value, viz., there is a load being transmitted through the component belt 20, the combined stresses *So* at the outer surface *Po* of the component belt 20 are larger in absolute value than the combined stresses *Si* at the inner surface *Pi* of the belt 20 as will be seen from the graphic illustration of Fig. 8D provided the effective radius *r* of each of the pulleys 1 and 2 is smaller than the radius of curvature ρ of the curved strip 19′. If the tensile stress S_t assumes a positive value and the effective radius *r* of each of the pulleys 1 and 2 is larger than the radius of curvature ρ of the curved strip 19′, then the combined stresses *Si* at the inner surface *Pi* of the component belt 20 are larger in absolute value than the combined stresses *So* at the outer surface *Po* of the belt 20. In any case, either the combined stresses *So* at the outer surface *Po* or the combined stresses *Si* at the inner surface *Pi* of the component belt 20 provide the maximum value of the combined stresses S of the component belt 20.

When the component belt 20 is travelling on and between the first and second pulleys 1 and 2, the radius of curvature of the belt 20 and accordingly the bending stress S_b induced in the belt 20 periodically vary. Along a straight path portion A—B of E—F from one of the pulleys 1 and 2 toward the other as indicated in Fig. 5, the component belt 20 has no bend so that the bending stress S_b remains at zero. Along each of arcuate path portions B—C, D—E, F—G and H—A through which the component belt 20 is about to turn on or leave the pulleys 1 and 2 as indicated in Fig. 5, the component belt 20 is arcuately curved with a radius of curvature continuously varying from infinity to the effective radius *r* of each of the pulleys 1 and 2 or vice versa so that the bending stress S_b at the outer surface *Po* of the component belt 20 varies from zero to S_{BT} or vice versa. Along each of turning path portions G—H and C—D through which the component belt 20 turns on the pulleys 1 and 2, respectively, as shown in Fig. 5, the component belt 20 is curved with a fixed radius of curvature equal to the effective radius *r* of each of the pulleys 1 and 2 so that the bending stress S_b at the outer surface *Po* of the belt 20 remains at S_{BT}. Thus, the bending stress S_b induced at the outer surface *Po* of the component belt 20 varies periodically as indicated by curve *Sb* in Fig. 9 as the component belt 20 travels along the path portions A—B— . . . —H—A as shown in Fig. 5.

On the other hand, the residual stress S_r and the tensile stress S_t remain constant throughout the path portions A—B . . . —H—A. Thus, the combined stresses *So* which are in play at the outer surface *Po* of the component belt 20 during operation of the belt-and-pulley mechanism embodying the present invention periodically vary as indicated by curve *So* in Fig. 9, provided the effective radius *r* of each of the pulleys 1 and 2 is smaller than the radius of curvature ρ. The curve *Sb* is obtained by adding the bending stress S_b to the tensile stress S_t and subtracting the residual stress S_r from the sum of the bending and tensile stresses S_b and S_t. It will be readily understood that the variation of the combined stresses *Si* at the inner surface *Pi* of the component belt 20 is indicated by a negative version of the curve *So*.

The curve *So* in Fig. 9 indicates that the combined stresses *So* oscillates periodically with a stress amplitude $E \cdot t/4r$. In this instance, the mean value *Sm* of the combined stresses *So* at the outer surface *Po* of the component belt 20 is represented by the mean value of the area defined between the curve *So* and the axis of abscissa representative of the time T.

On the other hand, the component belt 10 in the prior-art belt-and-pulley mechanism shown in Figs. 1 and 2 is subjected to the bending stress S_b and the tensile stress S_t alone. The combined stresses *So′* which are in play at the outer surface of the component belt 10 are thus given by the sum of the bending stress S_{BT} and the tensile stress S_t as indicated by curve *So′* in Fig. 9. The combined stresses *So′* also vary periodically with a stress amplitude $E \cdot t/4r$ similarly to the combined stresses So but have a mean value *Sm′* which is larger by the absolute value of the residual stress S_{RC} than the mean value *Sm* of the combined stresses So in the component belt 20.

Meanwhile, the fatigue limit of a metal subjected to the action of repeated stresses can be generally represented by curve K indicated in Fig. 10 in which the stress amplitude $E \cdot t/4r$ is plotted as ordinate *vs.* the mean stress S_M as abscissa. In Fig. 10, the coordinates of any points in the area "Q" above the curve K are values of the mean stress and the stress amplitude which may produce failure of the metal, while the area "R" below the curve K indicates the endurance range of the metal. It will be seen from the curve K that, as the mean stress applied to a material becomes larger, the material endures the more if the stress amplitude is unchanged. If thus, the relationship between the mean stress *Sm′* and the stress amplitude $E \cdot t/4r$ in the component belt 10 of the prior-art belt-and-pulley mechanism is

indicated at point *a* located in the area "Q" in Fig. 10, the relationship between the mean stress *Sm* and the stress amplitude $E \cdot t/4r$ in the component belt 20 in the embodiment of the present invention can be indicated at point *b* located in the area "R". This means that the component belt 20 in the embodiment of the present invention is more durable against the action of stresses than the component belt 10 of the prior-art belt-and-pulley mechanism described with reference to Figs. 1 and 2.

Due to the residual stress S_r induced in the component belt 20, the component belt 20 is subjected to a large tension resulting from the sum of the residual tensile stress S_{RT} and the tensile stress S_t at its inner surface *Pi* along each of the straight path portions A—B and E—F (Fig. 5). If the residual stress S_b is excessively large, the mean value of the combined stresses *Si* ($=S_{RT}+S_t$) at the inner surface *Pi* of the component belt 20 may become so large as to cause the component belt 20 to fracture.

The optimum value of the residual stress S_r is obtained when the combined stresses *So* at the outer surface *Po* of the component belt 20 along each of the turning path portions C—D and G—H with a radius of curvature equal to the minimum effective radius r_o of the pulleys 1 and 2 are equal to the combined stresses *Si* at the inner surface *Pi* of the component belt 20 along each of the straight path portions A—B and E—F. The optimum value thus obtained of the residual stress S_r gives a minimum value of the combined stresses which are in play at each of the inner and outer surfaces *Pi* and *Po* of the component belt 20 and, for this reason, makes the component belt 20 most durable against the action of stresses.

When the component belt 20 is making a turn with a radius of curvature equal to the minimum effective radius r_o of the pulleys 1 and 2, the bending stress S_{BT} appearing at the outer surface *Po* of the component belt 20 along each of the turning path portions C—D and G—H is given by

$$S_{BT}=E \cdot t/2r_o$$

and produces tension at the surface *Po*. On the other hand, the residual stress S_{RC} which is in play at the outer surface *Po* of the component belt 20 is given by $S_{RC}=-E \cdot t/2\rho$ and acts as a compressive stress as previously discussed. The combined stresses *So* at the outer surface *Po* of the component belt 20 along each of the turning path portion C—D and G—H are given as the sum of the bending stress S_{BT} and the residual compressive stress S_{RC}, hence

$$\begin{aligned} So &= S_{BT}+S_{RC} \\ &= E \cdot t/2r_o - E \cdot t/2\rho. \end{aligned}$$

The combined stresses *Si* which are in play at the inner surface *Pi* of the component belt 20 along each of the straight path portions A—B and E—F consist of the residual tensile stress S_{RT} so that

$$Si=S_{RT}=E \cdot t/2\rho.$$

when the combined stresses *So* and *Si* as above expressed are equal to each other, there hold the following relationships:

$$E \cdot t/2r_o - E \cdot t/2\rho = E \cdot t/2\rho$$
$$1/2r_o = 1/\rho$$

Hence, $\rho = 2r_o$.

From this it will be seen that the radius of curvature ρ with which the curved strip 19' (Fig. 4) to form the component belt 20 is preferably twice the minimum effective radius r_o of the pulleys 1 and 2.

While it has been assumed that the belt-and-pulley mechanism embodying the present invention is constructed and arranged similarly to the prior-art mechanism illustrated in Figs. 1 and 2, it will be apparent that the mechanism according to the present invention may be constructed and arranged similarly to the prior-art mechanism illustrated in Fig. 3.

Claims

1. A variable-pitch belt-and-pulley mechanism comprising two pulleys having a pair of frusto-conical inner faces forming therebetween a circumferential groove having a substantially trapezoidal cross section which is continuously variable in width so that each of the pulleys has a continuously variable effective radius, and

an endless belt assembly passed between the pulleys and comprising at least one belt structure including at least one flexible component belt of loop form having inner and outer surfaces and a series of carrier blocks disposed in contact with one another throughout the length of the belt structure and each having an outer surface portion which is held in frictional contact with the inner face of the belt structure and a pair of inclined side faces which are held in frictional contact with the frusto-conical inner faces, respectively, of each of the pulleys,

wherein the component belt of the belt structure has a residual tensile stress which becomes maximal at the inner surface of the component belt and a residual compressive stress which becomes maximal at the outer surface of the component belt.

2. A method of producing a flexible component belt for use in a variable-pitch belt-and-pulley mechanism comprising two pulleys each having a pair of frusto-conical inner faces forming therebetween a circumferential groove having a substantially trapezoidal cross section which is continuously variable in width so that each of the pulleys has a continuously variable effective radius, and an endless belt assembly passed between the pulleys and comprising at least one belt structure including at least one flexible component belt of closed loop form having inner and outer surfaces and a series of carrier blocks disposed in contact with one another throughout the length of the belt structure and each having

an outer surface portion which is held in frictional contact with the inner face of the belt structure and a pair of inclined side faces which are held in frictional contact with the frusto-conical inner faces, respectively, of each of the pulleys, wherein the component belt of the belt structure has a residual tensile stress which becomes maximal at the inner surface of the component belt and a residual compressive stress which becomes maximal at the outer surface of the component belt and wherein the component belt is produced by plastically deforming an elongated strip of ductile metal in such a manner that the strip is caused to curve with a predetermined radius of curvature and that the curved strip has inner and outer faces which are to constitute the outer and inner surfaces, respectively, of the component belt when the curved strip is rendered into endless loop form.

3. A method as set forth in claim 2, in which said predetermined radius of curvature is approximately twice the minimum effective radius of said pulleys.

4. A variable-pitch belt-and-pulley mechanism substantially as described with reference to, and as illustrated in, Figs. 5 to 8D of the accompanying drawings.

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